MODELING FIRES - THE NEXT GENERATION OF TOOLS

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INTRODUCTION

This paper discusses fire modeling and how it is changing. The examples will be based on the tools that are being developed at NIST, in the Building and Fire Research Laboratory, but the general concepts are universally true.

Modeling of fire, in the sense most understand it, is a relatively new discipline. Although Kawagoe[1] first proposed that one might be able to estimate the outcome of a fire scenario in the early fifties, and Emmons[2] actually tried to make it happen in the seventies, it wasn't until the early eighties that the science of fire and engineering applications became popular. Much of the impetus in the United States came from the Presidential Commission on Fire, America Burning[3], after which the Center for Fire Research was established. Subsequently, an the Federal Trade Commission developed a formal complaint that small scale testing did not adequately address the real behavior of materials. This led to an interest in tests which measured fire performance properties rather than simple classifications.

The project which followed that from the Products Research Committee[4], provided a systematic set of data which provided a benchmark for correlating data, and extrapolating beyond the current values.

Even at this point, the engineering consisted mostly of correlations and single line formulas. As useful as they might be, approximations at that level excluded much of the detail that is necessary to make good, long duration calculations. It was during the middle of the eighties that Tanaka[5] and Jones[6] showed how to do these calculations with the simplification coming from physical observation rather than forced by mathematical necessity.

These comments pertain primarily to what is called "zone" modeling today. There is a parallel track in computational fluid mechanics (CFD). That work has been going on a much longer time, and has a great deal of history behind it. However, this work has been devoted mostly to fluid mechanics and combustion. The former is a purely fluid mechanical problem, whereas the latter has a combined fluid mechanics and chemistry focus. The popular use of CFD modeling in fire is a very recent phenomenon. Although reactive flow has been studied in this realm for over two decades, the application to fire has been less than a decade. This will certainly change over the course of the next few years.

What is propelling CFD, and was the cornerstone of zone modeling, has been the rapid improvement in computational power. A factor of 1000 in the rate of computing, not including the increase in computer word size, together with a similar increase in mass storage as well as computer memory has allowed dramatic improvements in what can be accomplished. Even so, the increases in the computational power over the next decade will bring concomitant improvements in the precision with which estimates of the effects of fires on constructed facilities and people can be made.

The CFD technique will begin to encroach on the zone model territory within the next 5 to 10 years. There has been a rich history of the development of such codes, though primarily aimed at solving other problems, with the solution to fire problems thrown in when convenient. An example of these types of models is that of Rehm et. al.[7]

HISTORY OF ZONE MODELING AT BFRL

The focus of this paper is on tools which are being developed today for immediate use by the engineering community. For this reason, the zone model concept will be discussed in detail, with reference to CFD models when appropriate. By way of illustration, this paper will deal with the development of CFAST and the Hazard Methodology. This is one instance of actual deployment of computing resources to improve understanding of fire and to provide tools for engineers to make safer buildings.

Many such tools have evolved over this time frame. The French equivalent to CFAST is CTT. In Japan, there exists an performance equivalency, in Article 38 of the Building Standards Law, which uses engineering tools as an alternate to the prescriptive code requirements. Tanaka’s BRI model is used in this case, although FAST[8] is mentioned as well. France and Australia have similar provisions, with their references made to their own models. Once again, CFAST/Hazard is cited as an alternative. The United Kingdom and Germany use the performance concept, but give only general guidelines on how the calculations are to be done.

The development thread that has led to the present form of CFAST/Hazard began in 1983. Up until this time, a significant approximation had been made, namely that pressure would equilibrate so quickly that it was not necessary to calculate its time dependence. The means by which fire models were built until this time was to cast the conservation equations of mass, energy and momentum into ones for temperature and layer height, with the assumption that pressure equilibration was sufficiently fast that the dP/dt term (right hand side) could be set to zero and the equation solved as an algebraic equation. This was an important milestone in that Jones and Bodart showed that by including the pressure equation in the set of differential equations to be solved, one would arrive at the answer more quickly[9], the result would be more accurate, there would be less chance of spurious results and a wider set of problems could be solved. All subsequent models have adopted this philosophy and it has proven to be a good choice.

Over the past decade the fire program of the Building and Fire Research Laboratory (formerly the Center for Fire Research) has developed computer based models as a predictive tool for estimating the environment which results in a building when a fire is present. In the beginning, there were three of these models: FAST, FIRST and ASET. In 1985, development of the CCFM (Consolidated Computer Fire Model) was begun. It was originally intended to be a benchmark fire code, with all algorithms of fire phenomena available for experimentation. A change in direction was made in 1986 and it was subsequently developed as a prototype of a well structured model. In 1989, a decision was made that development of many computer programs was not the best possible course. Two programs resulted from that. The two were CFAST and FPETool.

CFAST is intended to operate on many platforms, be as error free as is humanly possible, be simple to run for simple problems, yet allow complexity where needed. The code is extremely fast. It is faster than any code of comparable completeness and complexity. It works on laptop personal computers, Unix workstations and supercomputers. It provides for extensive graphics for analysis with pre- and post-processing modules. It is extremely fast on single compartment cases, and with the data editor, there is tremendous flexibility. It is intended to be a complete, yet very fast, computer code for calculating the effects of fire on the environment of a building. It is particularly well suited for doing parameter studies of changes, both subtle and large, within a single compartment.

The phenomena developed over the past couple of years represent the practical endpoint for zone models. These include new phenomena and features as appropriate to continue the tradition of providing a state-of-the-art tool for hazard analysis for use by fire protection professionals. They fall into four areas: fire model, egress and tenability models, databases, and user interface / documentation.

The FPETool project was carried through as a basic DOS based text package until there was a paradigm shift in the fall of 1995. At that point it was determined that a better user interface was needed, and the "FIRE SIMULATOR" fire model was replaced by an interactive version of CFAST. The new user interface (a graphical user interface or GUI) was developed to ease the use of this and subsequent fire modeling tools. This is called FASTLite and is the prototype for future versions of CEdit and Hazard.

IMPROVEMENT IN CAPABILITY

There are a number of phenomena which have been added since the introduction of the FAST/CFAST/Hazard I. For example, we have implemented a ceiling jet algorithm[10] which takes into account heat loss from a fire placed in an arbitrary position within a compartment. The algorithm describes the theory and implementation of the algorithm which accounts for the off-center placement of the fire and its effect on heat transfer to the room surfaces. Recent work was to include the 3D location of the fire in a room. It has been demonstrated that the location of the fire had a significant impact on the wall, ceiling and upper layer temperature. This quantified the importance of detector siting and sensitivity on sensing the presence of fire. We hope to be able to continue work to include smoke and heat detectors in the model so that such studies can be conducted in a systematic manner, both for within compartment detection, as well as for detectors located in adjacent compartments.

Pyrolysis and flame spread algorithm now exist, although only for lateral and upward spread. The necessity for extending these concepts to horizontal spread lies in being able to treat mattresses and cable trays, as well as wall linings. A requirement to implement such an algorithm will be to improve the radiation model, which is discussed later. Finally, a general radiation model is now used. This is a ten wall model for the four upper wall segments, four lower wall segments, ceiling and floor. Numerically it is simplified to four segments, based on symmetry of the rectangular parallelepiped used in our zone model[11]. It is just slightly slower than the earlier extended ceiling algorithm, but the improvement in accuracy is significant.

THE USER INTERFACE

The salient problem with zone models is that they are inherently control volume or point source models. The derivation of the predictive equations makes the assumption that there is no dimensionality to the physical space. In order to relate these calculations of smoke filling volume to actual buildings, some relationship needs to be stated. This has led to a dichotomy in what can be calculated, and the means of specifying what is to be done. For the models themselves, this dilemma has mostly been solved. However, the user interface, that is the means for someone to specify what problem is to be solved, has lagged.

It is quite easy to generate a computer model that will deal with 50 or 100 rooms. The difficulty which this entails is generating the appropriate scenario. Prior to the work that is being discussed in this paper, the editor for the compartment configuration was text based. This is a holdover from the early days of modeling, but the change to Graphical User Interfaces (GUI's) is quite important and has been the impetus for making these tools behave as tools rather than imponderable computer applications. The material which I am going to show today is based on a two dimensional paradigm. It is a dramatic improvement in that all editing functions can be made available to each room and the visual feedback on what is being accomplished is immediate. This still leaves open the relationship between the compartments. The horizontal positioning which is observable says nothing about the way the compartments are related. We do have a prototype of this connectivity in the mechanical ventilation, but it too could be improved.

Our concept of a GUI will be embodied first in FASTLite and the CFAST shell. In the first instance, we will have a simple single file editing session. The long range plan is to allow editing of multiple sessions and concurrent execution of the model. In some ways this goes beyond our original goal of providing a simple filter to prevent egregious mistakes, but it will allow us to make the databases much more versatile without encumbering those using the methodology too much. We will extend the editor to include the graphics output as well as the people placement and specification of those items which affect the behavior of people. The new GUI's will present a graphical two dimensional representation of a building.

THE FUTURE IS CAD

What we see as the future is the use of Computer Aided Design (CAD) in developing building scenarios. An extremely important caution for those who develop such tools is to implement them in the simplest possible way. That is, using a full blown CAD system, which requires many hours of training, is not fruitful. Rather the thrust of the work should be to enable the person using the system to work as easily and mistake free as possible. This has been the real advantage of computer based tools: it is possible to build some error checking into them to filter out silly errors, and to show what the current state of the problem is.

MISSING

As might be expected, none of these models is complete. CFD models have the longest way to go in addressing the problems of ascertaining the effect that a fire will have on the environment in a building. However, there is sufficient verisimilitude with reality that the models will generally do better than intuition, so long as the one is predicting the outcome of the physical situation that is wanted.

There are many features which could be beneficially added, ways to make the use easier and more reliable and connectivity to reduce transcription and the concomitant errors that occur. Extending these tools to real time use in buildings, perhaps in conjunction with environment monitors, would be a useful approach.

Having said that not all phenomena are modeled, nor are the ones present all done equally well, it is important to have a recipe for how to proceed. For example, adapting an algorithm from a research paper is not straightforward. There are implications for the range of validity, as well as usefulness. Also, we must concern ourselves with the smoothness of correlations. An example of such a problem which we recently addressed is that of plume flow. We use the correlation of McCaffrey[12]. He divided the plume into three regions, depending on how much combustion occurs in each region. As it turns out, there were discontinuities at the transition points. In some cases this would cause the solver (numerical integrator) to slow down dramatically. Further, since the phenomena must be continuous in real life, his correlations were prima facia incorrect. The change to fix this was not large, but illustrates the some of the difficulty of making the transition from research to practice.

The quest is to provide a tool which will help improve the understanding of fires. This is not an attempt to make the application of models trivial, but rather to provide a mechanism to allow researchers, fire protection engineers, and others access to the most current understanding of the behavior of fires. Improvement in the physical basis of the model is the means to reach this goal. At the same time, it is hoped that it would be possible to allow more extensive calculations such as long corridors, three dimensional effects, and the use of faster computers, distributed processing, and automatic transfer of data. Although the concept of a more intuitive interface is a goal, there really is no such thing as an intuitive user interface. Our goal is to provide a tool which aids, and does not hinder, understanding of fire effects and phenomena.

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